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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DEPARTMENT OF CHEMISTRY

The Nitrogen and Humus Problem in Dry Farming

By R. W. THATCHER

BULLETIN No. 105

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THE PROBLEM

There are two principal factors which limit the productivity of any given tract of land or any particular agricultural section. These are: (a) the supply of moisture which is available for crop production at the season of the year when it is required by the growing crops, and (b) the available fertility or plant food in the soil in proper form so that crops can use it at the time when they need it for their development. There are other factors in production, such as the presence of favorable and the absence of injurious bacteria, suitable temperature conditions during the growing season, proper texture and physical condition of the soil, etc.; but these influence crop growth principally by their effect upon the moisture supply or availability of the plant food of the soil. So that, speaking generally, it may be said that the actual yield per acre of any given crop upon any particular tract of land in any one season will be detrmined by the supply either of available moisture or of available plant food, or, in rare instances, by a combination of these two limiting factors.

In any locality which receives an abundant moisture supply, either through natural rainfall or by irrigation, the yield of crops will be limited by the plant food or available fertility of the soil. On the other hand, in regions of scanty or unseasonable rainfall, soils are usually supplied with ample or more than sufficient available plant food to produce greater yields than the moisture supply will develop and the latter becomes the limiting factor in crop production.

In former years, when more agricultural land was available than there were settlers to occupy, farming was carried on only in regions of ample or nearly sufficient rainfall, and the only problems of productivity which were commonly recognized were those of fertility, and methods of farm practice were adopted or rejected primarily because of their effect upon the maintenance or increase of soil fertility. The land-owner planted his crop, and cultivated his soil so as to destroy weeds and to encourage development of available plant food, or added fertilizers, and ''trusted in Providence'' to furnish the rain at the proper season.

More recently, with the extension of farming operations into the semi-arid or ''plains'' regions, a type of farming has been developed which has for its chief object the best use of a limited or unseasonable precipitation of moisture. This system of farming is commonly known as ''dry-farming,'' or ''dry- land agriculture.'' Such a designation does not mean farming without moisture, of course; but has reference to a system of cropping and tillage which recognizes the moisture supply as the limiting factor in crop production and directs its operations toward the storage and conservation in the soil of unseasonable precipitation or the best utilization of a scanty supply of soil moisture.

In the older type of agriculture, the importance of a sufficient supply in the soil of organic matter of the right kind to furnish active humus and available nitrogen has long been recognized. The value of decaying vegetation in rendering available nitrogen has been so well known that the practice of growing leguminous crops to be plowed under as ''green manure'' and of direct applications of humus producing refuse such as farm-yard manures and animal wastes is regarded as a regular feature of older systems of farming.

''Dry-farming,'' on the other hand, has thus far almost wholly disregarded the older practices in this respect, and has given its entire attention to moisture conservation and utilization. Recent researches, however, have shown that the humus of the soil is so influential a factor in its water-holding capacity and successful tillage that it is now known that the humus content of the soil is fully as important in dry-farming regions and practices as in the older types. Deficiency in humus affects such soils injuriously in at least three ways: first, by reducing its fertility because of scanty supply of nitrogen; second, by decrease in water-holding capacity, which is of so much importance to dry-farming land; and third, by a decrease in the friability of the soil, rendering it harder to till and to get into proper shape for seeding.

Unfortunately, most semi-arid soils are poorly supplied with vegetable matter, because of the scant rainfall and consequent sparse growth of native vegetation. The small supply is likely, also, to be near the surface of the ground, and not to extend to any great depth in the soil.

Results Obtained Elsewhere

The importance of the humus problem in dry-farming has led a number of investigators to study the effect of the present methods of dry-farm tillage upon the store of humus in the soil. The characteristic features of dry-land farming are: the growing of a single cereal crop, with no "hoed-crop" or legume in rotation, and frequent seasons of "summer-fallow," or summer-tilled, uncropped land. What effect this system will have upon the nitrogen and humus content of the soil, is a matter worthy of serious consideration, and is receiving considerable attention by experiment station investigations.

Snyder[1] of Minnesota found that continuous cropping, with or without summer-fallowing, produced a very rapid decrease in the humus and nitrogen content of the soils of that State. His results indicated, also, that there was a much greater loss from idle land during summer-fallowed seasons than was removed by crops grown upon the same lands in other years.

Alway's[2] results showed a large loss of organic matter, humus and nitrogen from soils cropped by dry-farming methods.

Alway and Trumbull[3], in Nebraska, found that there is generally a decreased percentage of nitrogen in cultivated soils as compared with the virgin soil in adjacent fields, although occasional exceptions to this were noted. The greatest losses of nitrogen were found in soils which had been given frequent summer-fallow cultivation.

Ladd[4], of North Dakota, reported a heavy loss of nitrogen, humus, and organic matter from soils in this state which had been farmed for a considerable period of time with frequent bare summer fallow cultivations.

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[1] Minn. Exp. Station, Bulletins Nos. 30-41-53-65-70-94.
[2] Neb. Exp. Station, Bulletin No. 111.
[3] Jour. Ind. and Eng. Chem. Vol. II, No. 4, p. 135.
[4] No. Dak. Exp. Sta. Bulletins Nos. 24-32-35-47.

Stewart[5], of Utah, found that the cultivated soils of the Cache Valley in that State, which have been dry-farmed for from twelve to thirty years, contain more nitrogen and humus than adjacent virgin soils, particularly in the surface layers.

Bradley[6] found that in Eastern Oregon the virgin and adjacent cultivated lands contained about equal amounts of nitrogen, but that the carbon content of the cultivated soils was lower than that of adjoining virgin soils.

Purpose of the Investigation

In view of the conflicting evidence cited above, and particularly since the results obtained in States west of the Rocky Mountains, where the annual precipitation comes during the winter months and the summer is the "dry season," apparently lead to different conclusions than those obtained by investigations in the Great Plains area of the Mississippi Valley, where summer precipitation is the rule, it seemed desirable to make a study of this matter in Eastern Washington.

There are two possible methods of investigating the effect of dry-farming methods upon the composition of the soil. The first, namely, the analysis of the soil at the beginning of a ten-year, or longer, period of tillage and another analysis of the same soil at the close of the period, is not available to us at the present time, as no preliminary analyses of soils from a definitely described location, with an accurate subsequent cropping history of the land, were available. We, therefore, choose the second possible method, namely, the analysis of carefully selected adjacent cultivated and virgin soils, with the assumption that any changes in composition which might be discovered are due to the cultivation and cropping of the land.

Collection of Samples

To Mr. V. R. Hyslop, a Senior student in the department of agriculture of the State College of Washington, was assigned the task of collecting and analyzing the soil samples. One set was collected on the College Farm at Pullman, as representative of the district of heaviest annual rainfall in the "wheat-belt" of Eastern Washington, the rainfall records showing an average annual precipitation of twenty-three inches at this place. A second set as collected at Deep Creek (average annual precipitation eighteen inches) representing th district of medium rainfall. A third set was taken at Almira (average precipitation twelve inches per annum) representing very light rainfall conditions. At each point, several different typical locations were chosen for sampling, so as to get representative samples from different slopes of land with their accompanying variations in soil character. The prevailing soil type over the entire "wheat-belt" is a fine silt loam composed of decomposed basalt intimately mixed with variable proportions of decaying bunchgrass and sagebrush vegetation.

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[5] Utah Exp. Station, Bulletin No. 109.

[6] Jour. Ind. and Eng. Chem. Vol. II, No. 4.

At each point which was to be sampled, a trench six feet long, two feet wide, and four feet deep, was dug and one side cut smooth. From this side a slice of soil was cut to the full depth, the soil from each foot in depth being preserved as a separate sample. Precisely similar trenches were dug at distances of not to exceed thirty feet apart, one in cultivated land and the other in virgin soil, care being exercised to see that the "lay-of-the-land" was such as to indicate originally uniform conditions.

The samples of cultivated soil from Pullman were from a tract which has been under cultivation for about thirty years, during the first twenty-five of which the land was cropped to wheat with alternate summer fallowing except for an occasional oat crop. During the last five years a rotation of wheat, corn, and oats has been followed. The Deep Creek soils were from a farm which has been cropped for twenty-three years to wheat with alternate summer fallowing. The Almira samples were from land which was brought under cultivation twelve years ago and has borne six wheat crops with six summer fallow seasons.

Results of Analysis

The samples were prepared for analysis, and determinations of their hygroscopic moisture, volatile and organic matter, humus, and nitrogen percentages made according to the official methods of the Association of Official Agricultural Chemists, by Mr. Hyslop.

The results of the analyses are shown in the following tables:

Table I. Results of Analyses—Pullman Samples

Kind of Land	Description of Samples	Organic Matter %	Humus %	Nitrogen %
Hill top	Virgin, First foot	6.71	2.01	0.143
	Virgin, Second foot	5.73	0.80	0.080
	Virgin, Third foot	4.90	0.60	0.064
	Cultivated, First foot	6.45	1.77	0.133
	Cultivated, Second foot	5.48	0.63	0.084
	Cultivated, Third foot	4.62	0.38	0.043
South slope	Virgin, First foot	5.67	1.80	0.155
	Virgin, Second foot	4.50	1.04	0.088
	Virgin, Third foot	5.45	0.61	0.065
	Cultivated, First foot	5.57	1.52	0.145
	Cultivated, Second foot	4.35	0.85	0.081
	Cultivated, Third foot	4.10	0.64	0.045
Bottom land	Virgin, First foot	8.13	3.05	0.229
	Virgin, Second foot	6.71	2.40	0.150
	Virgin, Third foot	6.17	1.77	0.113
	Virgin, Fourth foot	5.42	1.43	0.091
	Cultivated, First foot	7.43	2.83	0.221
	Cultivated, Second foot	6.15	2.09	0.124
	Cultivated, Third foot	4.93	1.59	0.091
	Cultivated, Fourth foot	4.37	1.19	0.072

Table II. Results of Analyses—Deep Creek Samples

Kind of Land	Description of Samples	Organic Matter %	Humus %	Nitrogen %
Hill top	Virgin, First foot	7.50	2.14	0.190
	Virgin, Second foot	6.21	2.07	0.134
	Virgin, Third foot	4.71	1.53	0.097
	Virgin, Fourth foot	6.29	0.96	0.068
	Cultivated, First foot	7.01	2.07	0.162
	Cultivated, Second foot	4.68	0.65	0.078
	Cultivated, Third foot	4.71	0.60	0.047
	Cultivated, Fourth foot	5.32	0.96	0.050
North slope	Virgin, First foot	6.87	2.20	0.172
	Virgin, Second foot	5.07	1.44	0.101
	Virgin, Third foot	4.85	1.24	0.073
	Virgin, Fourth foot	4.25	0.82	0.063
	Cultivated, First foot	7.68	2.70	0.190
	Cultivated, Second foot	4.74	1.56	0.124
	Cultivated, Third foot	4.45	1.29	0.119
	Cultivated, Fourth foot	3.71	0.83	0.051
South slope	Virgin, First foot	6.48	1.84	0.157
	Virgin, Second foot	5.06	1.20	0.098
	Virgin, Third foot	4.08	0.73	0.070
	Virgin, Fourth foot	3.60	0.60	0.052
	Cultivated, First foot	7.03	2.40	0.148
	Cultivated, Second foot	5.12	1.35	0.093
	Cultivated, Third foot	4.28	0.85	0.074
	Cultivated, Fourth foot	4.12	0.65	0.052
Bottom land	Virgin, First foot	7.47	2.48	0.207
	Virgin, Second foot	6.67	2.30	0.185
	Virgin, Third foot	4.67	1.31	0.087
	Cultivated, First foot	5.80	1.76	0.156
	Cultivated, Second foot	4.44	1.32	0.101
	Cultivated, Third foot	3.83	0.80	0.056

Table III. Results of Analyses—Almira Samples

Kind of Land	Description of Samples	Organic Matter %	Humus %	Nitrogen %
Hill top	Virgin, First foot	4.25	0.77	0.089
	Virgin, Second foot	3.76	0.38	0.076
	Virgin, Third foot	3.63	0.35	0.043
	Cultivated, First foot	4.36	0.98	0.091
	Cultivated, Second foot	3.96	0.67	0.076
	Cultivated, Third foot	2.96	0.36	0.045
Bottom land	Virgin, First foot	5.26	1.17	0.135
	Virgin, Second foot	5.00	0.97	0.108
	Virgin, Third foot	4.28	0.71	0.075
	Cultivated, First foot	5.48	1.33	0.132
	Cultivated, Second foot	4.66	0.88	0.089
	Cultivated, Third foot	4.18	0.64	0.068

The data presented in these tables show very clearly that the organic matter, humus, and nitrogen content of the "wheat-belt" soils in Eastern Washington are greater near the surface and decrease regularly with the depth. The depth to which the samples were taken, in each case, was the extreme depth to which the root zone of crops appeared to extend, and the total supply of these constituents which may be considered as a factor in crop production.

There is no evidence in these figures of a greater concentration of humus and nitrogen in the surface layers in the cultivated soils than in virgin soils. Thus, this phenomenon, as reported by Stewart in his study of dry-farmed soils in Utah and explained by him as probably due to the bringing to the surface of nitrogen from lower depths by deep-rooting dry-land crops, and concentration in the tilled layer of humus and nitrogen by decaying stubble, does not appear to occur in Washington wheat lands. It may perhaps be true that Utah farmers are careful to plow into their lands all the stubble possible, rather than to burn it off before plowing, as has been the general practice of Washington wheat growers.

The general rule that the percentage of organic matter, humus, and nitrogen is higher in the virgin soils than in the corresponding cultivated soils is also apparent. This is shown somewhat more clearly in Table IV, in which the average percentage for each of these constituents for the entire depth to which samples were taken is shown, in each case.

Table IV. Comparison of Humus and Nitrogen Content of Virgin vs. Cultivated Soils

Locality	Kind of Land	Soil Treatment	Humus %	Nitrogen %
Pullman	Hill top	Virgin	1.14	0.096
		Cultivated	1.00	0.087
	South slope	Virgin	1.15	0.103
		Cultivated	1.00	0.090
	Bottom land	Virgin	2.16	0.146
		Cultivated	1.93	0.130
Deep Creek	Hill top	Virgin	2.16	0.146
		Cultivated	1.07	0.084
	North slope	Virgin	1.43	0.105
		Cultivated	1.59	0.121
	South slope	Virgin	1.09	0.094
		Cultivated	1.31	0.092
	Bottom land	Virgin	2.03	0.160
		Cultivated	1.29	0.104
Almira	Hill top	Virgin	0.50	0.069
		Cultivated	0.67	0.071
	Bottom land	Virgin	0.95	0.106
		Cultivated	0.95	0.096

From Table No. IV it appears that all the soils which were sampled at Pullman show marked decreases in humus and nitrogen in the cultivated soils as compared with adjoining virgin soils. The hill-top and bottom-land soils from the Deep Creek section show very marked decreases, while the soils from the slopes show increases in these constituents in the cultivated lands. The Almira soils, as might be expected from the short time which they have been under cultivation, do not show any very significant differences between cultivated and virgin land.

Assuming that the observed differences between adjacent virgin and cultivated lands are due to the effects of the cropping of the land, it may be said that these results show, in general, a significant reduction in the organic constituents of the soil by the present methods of "dry-farming" operations.

Causes and Remedies for Losses of Humus and Nitrogen

The question naturally arises whether these observed losses are due to the actual removal of these constituents from the soil by the crop, or are, in part, at least, losses in other ways caused by the methods of tillage and cropping employed. There is no way to measure changes in the humus content, or total organic matter of soil resulting from the growth of a crop upon it, as the organic matter of the crop is largely, if not wholly, built up by the crop itself in growing, and not taken from the soil. Wheat, however, takes all the nitrogen which it uses directly from the soil; and if the yield of crop is known the actual amount of nitrogen taken from the soil by the crop can be easily calculated. Exact crop records from the various fields from which the above sample came are not available, but the average yield from such lands in these localities is well known. Assuming the average yield of crops to have been grown on the fields in question, and computing the total losses of nitrogen from the soils of each locality, as shown in Table IV, we have the following results:

Table V. Losses of Nitrogen from Soil

Soil from........	Years of Cropping...	Total Loss of Nitrogen Lbs. per acre......	Nitrogen Removed by Crop. Lbs. per acre.	Net Loss of Nitrogen Lbs. per Acre.....
Pullman	30	1630	1200	430
Deep Creek	23	2780	900	1880
Almira	12	600	250	350

It appears, therefore, that there have been actual losses of nitrogen over and above that removed by the crops. Without better crop records than are available, it is impossible to definitely correlate these with any particular method of tillage, rainfall condition, or other local factors.

There are at least three possible ways by which losses of nitrogen and humus from soils may occur. First, through bacterial and chemical activities, they may become soluble in water and leach from the soil by drainage. Second, they may be lost by surface erosion, by wind or water. Third, oxidizing and denitrifying bacteria may convert them into gases, which escape into the air. Under dry-farming conditions, where the annual precipitation is practically all stored in the upper layers of soil, there is little likelihood of drainage losses. On hilly land, such as is common throughout the wheat belt, there is opportunity for some surface erosion, causing a movement of various soil constituents down the slopes. The higher percentages of organic constituents in the bottom land samples and very noticeably lower percentages of these in the hill-top samples, as shown in the tables above, indicates that this has actually taken place during the periods of soil formation. The ratio of these percentages at different slopes does not appear to be different in the virgin and cultivated soils, however, so that the cultivation has not, as yet materially affected this movement so as to produce losses from this cause on hillside soils due to tillage methods. It is probable, therefore, that the observed losses are due almost entirely to volatilization in gaseous form of these organic soil constituents. That bare, summer-tilled land offers conditions favorable to oxidation of soil organic matter is now generally recognized. This is especially true where the summer tillage is carelessly done. The practice, which was formerly common in Eastern Washington, of ''summer-fallowing'' simply by plowing the land, often when it was so dry as to turn up very cloddy and loose, with little or no subsequent cultivation, afforded conditions particularly favorable for such losses. It is probable that better methods of summer tillage will decrease the losses from this source.

The fact that some of the soils which were examined showed a gain in humus and organic matter in the cultivated land, even though they decreased in nitrogen content, indicates that it is possible, by plowing under practically all the straw produced by the growing wheat, actually to increase the humus content of the soil. Clearly, this should be possible, because each growing crop produces large quantities of vegetable matter, and, if only the grain is sold and the remainder of the crop plowed under, the organic matter of the soil might actually be increased. But, since most of the nitrogen of the crop goes into the grain and is, therefore, sold away from the farm, a continuous decrease in soil nitrogen must result, even if there are no losses in addition to crop removals.

Unfortunately, in most dry-farming districts, the value of humus in the soil, and the importance of plowing into it all vegetable matter possible has not been known, and stubble, straw, etc., has nearly always been burned instead of plowed under. This was not done simply as a matter of convenience, but generally because the putting at the bottom of the furrow slice of a thick layer of manure, stubble, or straw, was almost invariably found to cause the soil to dry out badly during the next season and so make the crop suffer for moisture or "burn" more or less disastrously.

It has not been discovered, however, that if vegetable matter on the surface of the ground is thoroughly chopped up and mixed with the surface layer of soil, it can be plowed under with perfect safety, even in the very arid sections, where the decay of such matter in the soil is necessarily slow.

Recommendations

As conclusions from the results of these and similar investigations, there may properly be presented here the following quotation from the report of the Committee on the Maintenance of Fertility under Strictly Dry-Farming Conditions, of which committee the author of this bulletin was chairman.

"The humus supply of the soil may be increased by regularly plowing under the stubble and straw which is grown on the land, supplemented by any green cover crop which conditions will permit to grow during the late fall or early spring months. All such material should be plowed under as deeply as possible, and should preferably be chopped up and mixed with the soil by thorough discing before plowing. Treated in this way, it can be put into the ground in good shape to decay and with the least possible danger of causing the soil to dry out so that the following crop will 'burn out.' Crops grown on lands which have their humus supply deep in the soil will naturally develop deeper rooting-systems and will be able to withstand drought and to draw larger supplies of plant food.''

''The leguminous crops are the greatest known soil renovators and the best and cheapest source of humus and nitrogen for green manuring purposes, but, unfortunately, over much of our western country the conditions which make dry-farming methods of cultivation necessary, also make it hard to grow the leguminous crops successfully or profitably. One of the important fields of investigation in dry farming is, therefore, the ascertaining of methods by which legumes may be grown to be plowed under for the purpose of increasing the supply of these constituents in which our dry-lands are most seriously deficient.''

''Alfalfa is at present the only legume which appears to have any very general applicability to dry-farming conditions. But alfalfa is not well adapted to short rotation systems. To grow this crop profitably and to derive the most benefit from it to the soil, it must stand for several years before being plowed down and must be at its maximum growth when turned under. This necessarily means a long rotation system, and one which must be carefully worked out in each individual locality in order to properly utilize all the available land each season and to insure a proper balance of crops produced.''

''On dry-farming lands whose chief characteristic is deficiency in humus and nitrogen, farm manure is of exceptionally high value as a soil renovator. Every available ton of manure should be carefully husbanded and utilized by plowing deeply into the land after first scattering it on the surface and discing thoroughly. The supply of manure should be increased as largely as possible by feeding livestock on the farm. The kind of livestock and the methods of feeding will be determined by local conditions, but the value of the manure in adding to the permanent fertility of the soil should always lead the owner of dry-farming lands to consider more than temporary market fluctuations in determining whether to continue or inaugurate feeding systems.''

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